# Technology for the UVOIR Telescope

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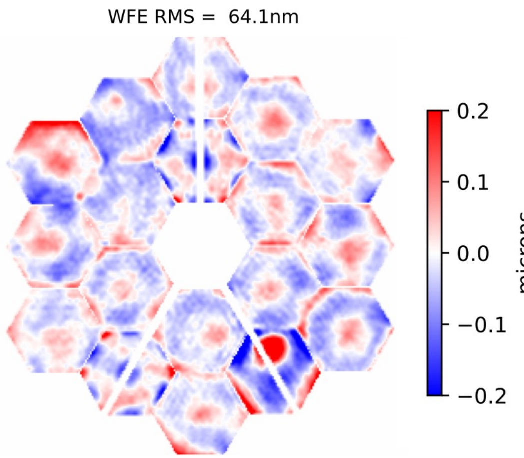
1/10/23

# JWST Performance nearly 2x spec Gives High Confidence a .5um diffraction limited telescope is feasible

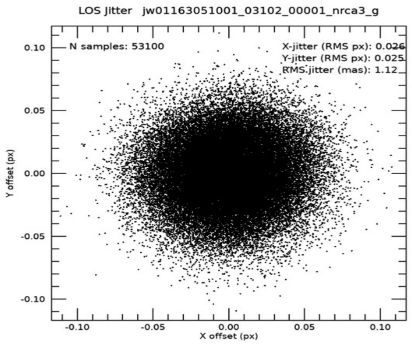
**Telescope ~ 65 nm rms**
**Telescope + SIs ~ 70-130 nm**




As of July 12th

λ/14 at 1.1 µm
λ/25 at 2.0 µm
λ/100 at 10 µm…

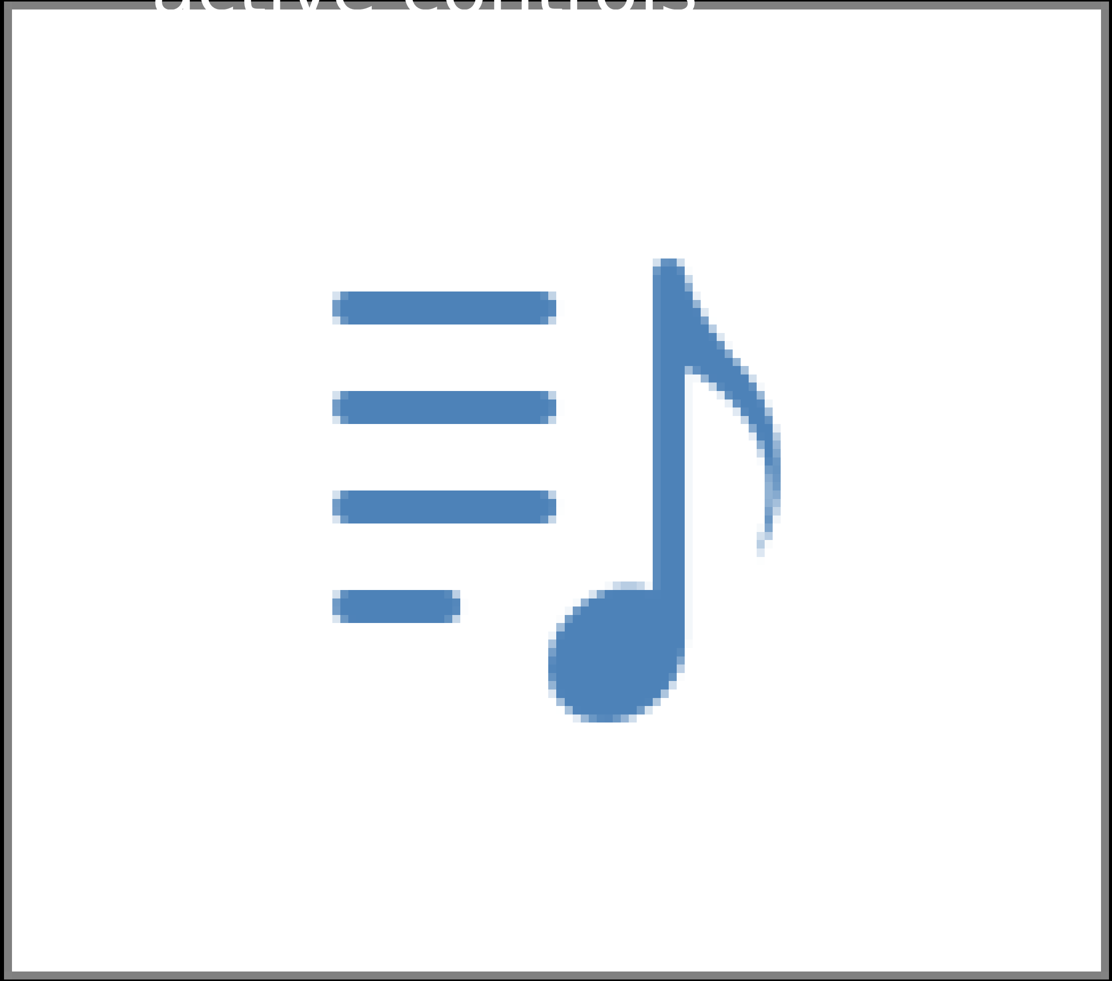
**Absolute pointing < 0.2”**
**Line of sight jitter ~ 1 mas**
**Dither precision ~2-4 mas**




No measurable vibration from cryocooler or reaction wheels

- Telescope performance is dominated by the primary mirror
  - WFE improvements needed for static WFE well within the state of the art (see “End-to-end assessment of a large aperture segmented Ultraviolet Optical Infrared (UVOIR) Telescope architecture” Feinberg, et al, SPIE/2016)
  - HWO is expected to be diffraction limited at .5um or about 37.5nm RMS WFE
- JWST’s 1 mas stability with simple isolation and 1hz fine steering loop
- Micrometeoroids can be reduced 100x with a baffle

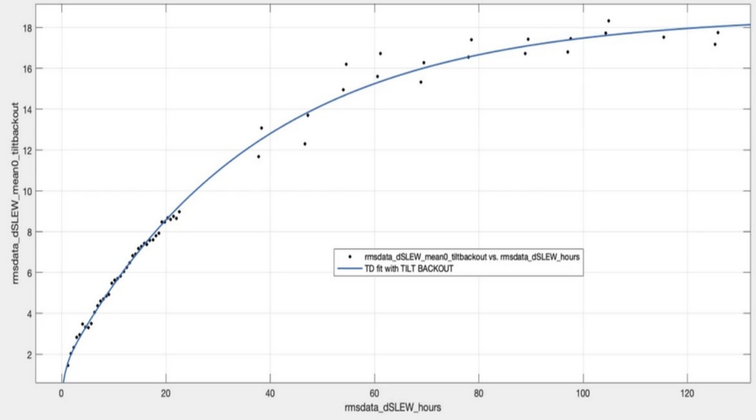
# JWST passive thermal stability defines upper bounds for active controls



Short Term Oscillations result from heaters used on instrument electronics panels connected to PM with .5K deadband

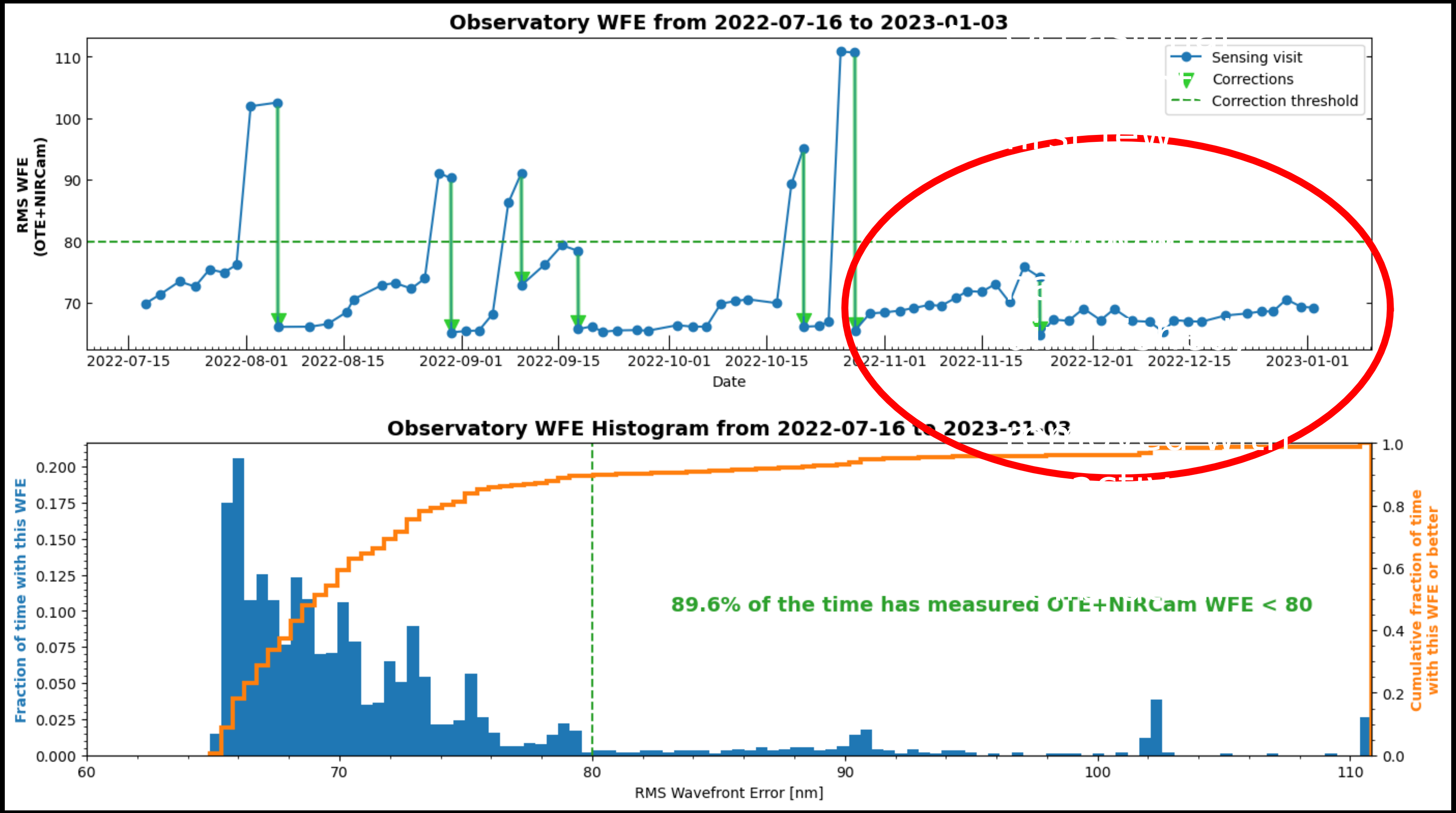
- BST predicts 1mK class control

Alden Jurling, Joe Howard (NASA GSFC)




18 nm RMS WFE over 8 days after ne worst case slew

# No significant tilt events in nearly 2.5 months




nt tilt events are defined as large enough to warrant WFE correction

al tilt events the first few months after cooldown have diminished, can be removed with an active loop or

# Habex Telescope Technologies (2019 assessment)

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | ≤1 m of the line of sight | | |
| Large Mirror Fabrication | Large monolith mirror that meets tight surface figure error and thermal control requirements at visible wavelengths | *Section 11.3.1.1* | • 4.2 m diameter, 420 mm thick blanks standard<br>• Schott demonstrated computer-controlled-machine lightweighting to pocket depth of 340 mm, 4 mm rib thickness on E-ELT M5 and 240 mm deep/2 mm thick rib on Schott 700 mm diameter test unit | • 4.04 m diameter substrate<br>• 3–4 mm ribs, 14 mm facesheet, and pocket depth of 290 mm for 400 mm thick blank<br>• Aerial density 110 kg/m²<br>• <5 ppb/K CTE homogeneity<br>• First mode ≥60 Hz | 4 | 4 |
| | | | • Wavefront stability: 25 nm RMS for HST in LEO<br>• Wavefront error of WFIRST-like primary mirror (spatial frequency cycles/beam diameter: nm RMS):<br>▪ 0–7 cy/*D*: 6.9 nm RMS<br>▪ 7–100 cy/*D*: 6.0 nm RMS<br>▪ >100 cy/*D*: 0.8 nm RMS | cycles/beam diameter: nm RMS):<br>▪ 0–7 cy/D: 6.9 nm RMS<br>▪ 7–100 cy/D: 6.0 nm RMS<br>▪ >100 cy/D: 0.8 nm RMS | | |
| Large Mirror Coating Uniformity | Mirror coating with high spatial uniformity over the visible spectrum | *Section 11.3.1.2* | • Reflectance uniformity <0.5% of protected Ag on 2.5 m TPF Technology Demonstration Mirror<br>• IUE, HST, and GALEX used $MgF_2$ on Al to obtain >70% reflectivity from 0.115 µm to 2.5 µm<br>• Operational life: >28 years on HST | • Reflectance uniformity <1% over 0.45–1.0 µm<br>• Reflectivity comparable to HST:<br>▪ 0.115–0.3 µm: ≥70%<br>▪ 0.3–0.45 µm: ≥88%<br>▪ 0.45–1.0 µm: ≥85%<br>▪ 1.0–1.8 µm: ≥90%<br>• Operational life >10 years | 4 | 5 |
| Laser Metrology | Sensing for control of rigid body alignment of telescope front-end optics | *Section 11.3.2.1* | • Nd:YAG ring laser and modulator flown on LISA-Pathfinder<br>• Phase meters flown on LISA-Pathfinder and Grace Follow-On<br>• Sense at 1 kHz bandwidth<br>• Thermally stabilized Planar Lightwave Circuit at TRL 6. Thermal stability measured, which could provide uncorrelated per gauge error of 0.1 nm | • Sense at 100 Hz bandwidth<br>• Uncorrelated per gauge error of 0.1 nm | 5 | 6 |

Assumed a 4m monolith

# LUVOIR Telescope technologies (2019 assessment)

**Table 11-2.** *Technology components in the ultra-stable segmented telescope technology system.*

| Section | Technology Component | Implementation Options | State of the Art | Capability Needed | FY19 TRL | In LUVOIR Baseline? |
|---|---|---|---|---|---|---|
| 12.2.2.4 | Mirror Substrate | Closed-back ULE (rigid body actuated) | 7.5 nm RMS surface figure area with no actuated figure correction | ~5 nm RMS surface figure error<br>> 400 Hz first free mode<br>19 kg/m² areal density | 5 | ✓ |
| | | Closed-back ULE (surface figure actuated) | < 200 Hz first free mode<br>~10 kg/m² areal density | | 4 | |
| | | Open-back Zerodur (rigid body actuated) | Meets wavefront error requirement, but first mode and areal density are challenges | | 4 | |
| 12.2.2.6 | Actuators | Combined piezo/ mechanical | JWST mechanical actuators; Off-the-shelf PZT actuator with 5 pm resolution | > 10 mm stroke<br>< 10 pm resolution<br>< 1 pm / 10 min creep<br>Long lifetime | 3 | ✓ |
| | | All-piezo | 20 mm travel with 5 nm coarse resolution and 5 pm fine resolution | | 3 | |
| 12.2.2.8 | Edge Sensors | Capacitive | 5 pm in gap dimension, 60 Hz readout | <4 pm sensitivity at 50–100 Hz rate (control bandwidth of 5–10 Hz) | 3 | ✓ |
| | | Inductive | 1 nm / sqrt(Hz) for 1–100 Hz in shear; 100 nm / sqrt(Hz) for 1–10 Hz in gap | | 3 | |
| | | Optical | 20 pm / sqrt(Hz) up to 100 Hz | | 3 | |
| | | High-speed Speckle Interferometry | < 5 pm RMS at kHz rates; requires center-of-curvature location and high-speed computing | | 3 | |
| 12.2.2.9 | Laser Metrology | Laser truss with phasemeter electronics | Planar lightwave circuit; 0.1 nm gauge error; LISA-Pathfinder heritage laser | < 100 pm sensitivity at 10 Hz rate (control bandwidth of 1 Hz) | 4 | ✓ |

**Table 11-3.** *Technology components in the ultraviolet instrumentation technology system.*

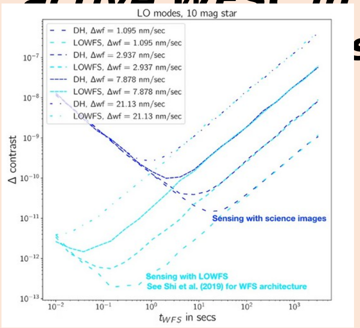
| Section | Technology Component | Implementation Options | State of the Art | Capability Needed | FY19 TRL | In LUVOIR Baseline? |
|---|---|---|---|---|---|---|
| 12.2.3.4 | Far-UV Broadband Coating | Al + eLiF + $MgF_2$ | Meets performance requirements, but requires demonstration on meter-class optics; requires validation of uniformity, repeatability, environmental stability | >50% reflectivity (100–115nm)<br>>80% reflectivity (115–200nm)<br>>88% reflectivity (200–850nm)<br>>96% refelctivity (> 850nm)<br>< 1% reflectance nonuniformity (over entire primary mirror) over corongraph bandpass (200–2000 nm) | 3 | ✓ |
| | | Al + eLiF + $AlF_3$ | | | 3 | |
| | | Al + eLiF | Meets performance requirements, but is environmentally unstable | | 5 | |

# ULTRA-TM (Ball/NG/L3 Harris) Recent Progress

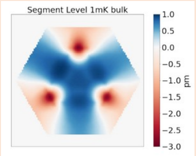
## CORONAGRAPH SENSITIVITES

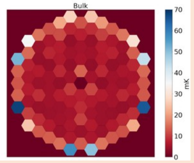
***Calculate contrast stability vs. spatial-temporal domain, active WFSC in coronagraph,***

***se***





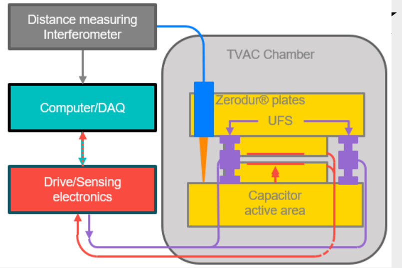


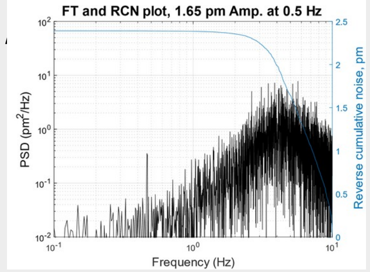



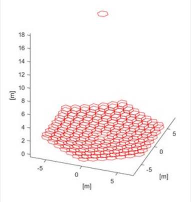

Key Result: Derived allocations for system stability budget, set necessary performance for systems/ subsystems/components, used to

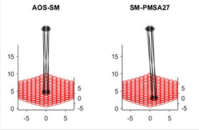
## SEGMENT SENSING AND CONTROL

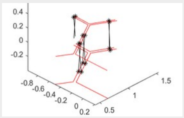
***Demonstrate picometer-level edge sensor and actuator components with flight-traceable designs.***

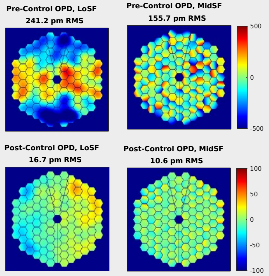




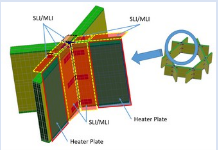


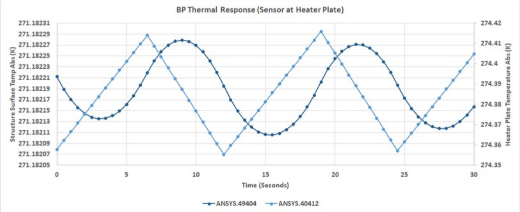

Key Result: Achieved 2.5 pm RMS closed loop sense/actuate residual from 0.01-10 Hz.

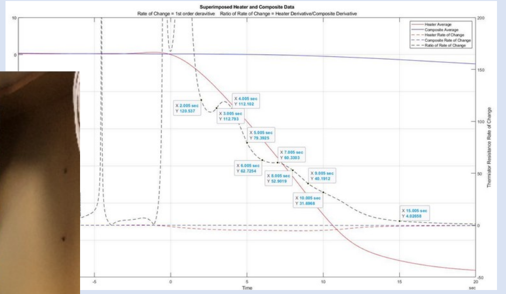
Developed flexible time domain simulation

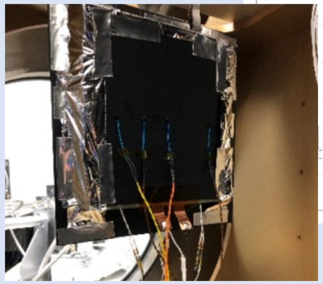
## THERMAL SENSING AND CONTROL

***Develop a radiative heating approach with stability in the mK regime***



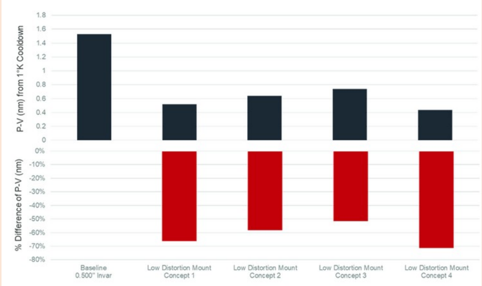


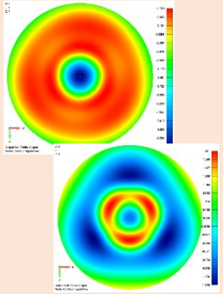
Key Result: Modeling and hardware demo of sub-mK thermal stability from rigid heater-integral-to-composite heater panel on structure element. Identified novel

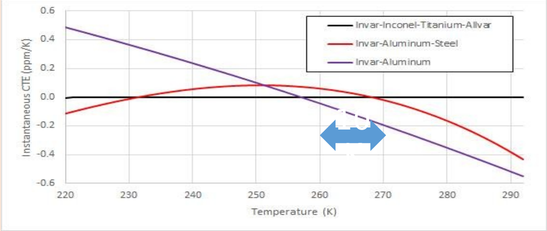
# ULTRA-TM Progress (Continued)

## STABLE MIRROR MOUNTING

***Design of novel mount pads, struts with improved passive stability to reduce mirror***



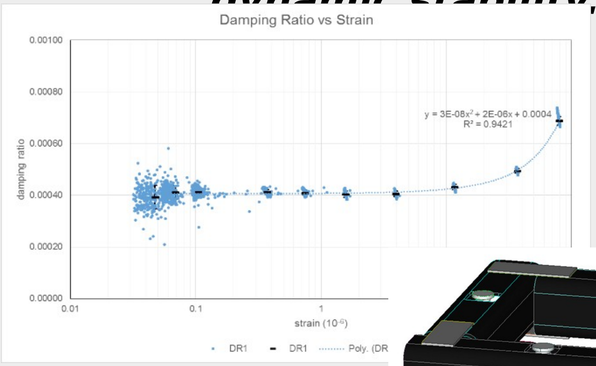


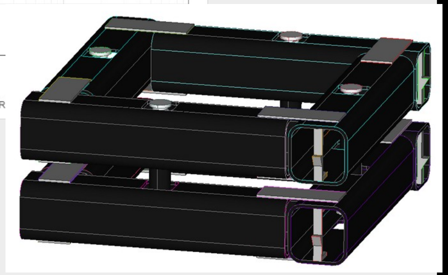

<u>Key Result</u>: Design and hardware demo of novel pad geometry with predicted 15-20X reduction in SFE distortion over solid pad.

Developed strut design with metal

## STABLE STRUTURES – LATCHING AND DAMPING

***Increase damping in large structures with foil treatment. Re-design latches to improve passive thermal & dynamic stability,***

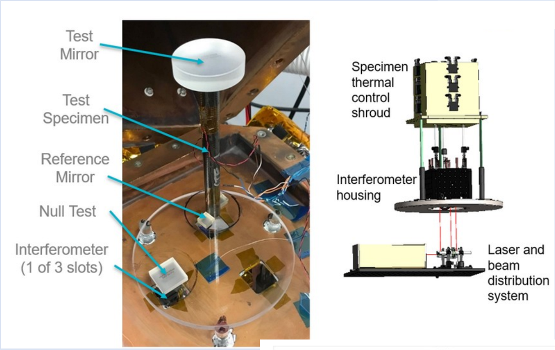


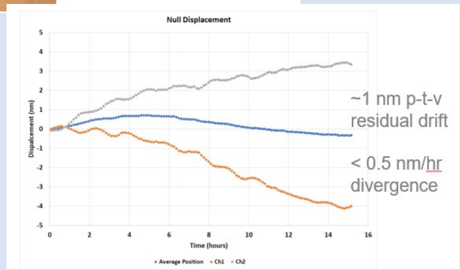



<u>Key Result</u>: Hardware demo showed foil appreciably increased damping ratio in composite coupons. Hardware demo of latchplane test article showed new design reduces deformation by several orders of

## MATERIAL PROPERTY METROLOGY

***Reduce uncertainty in measured CTE/CME of composites by 100X***




<u>Key Result</u>: 10X improvement in displacement measurement. Improved isolation from lab environment. Completed analysis of alignment stability on

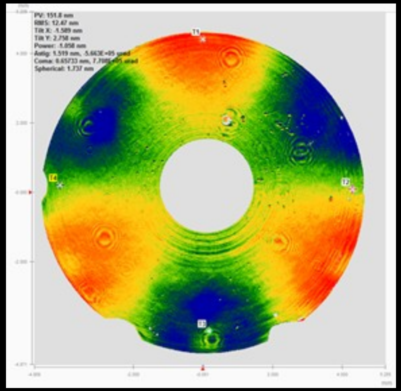
# Predictive Thermal Control (PTC) Technology to Enable Thermally Stable Telescopes

PI: H. Philip Stahl / MSFC
Co-I Thomas Brooks / MSFC


## *Objectives and Key Challenges:*

- Validate models that predict thermal optical performance of real mirrors and structure based on their structural designs and constituent material properties, i.e. CTE distribution, thermal conductivity, thermal mass, etc.
- Derive thermal system stability specifications from science-driven wavefront-stability requirement
- Demonstrate utility of PTC system for achieving thermal stability

PTC control system achieved 2K accuracy with 2mK stability of 1.5-m AMTD-2 ULE® mirror



Thermal zones able to impose 150 nm of trefoil

## *Significance of Work:*

- Thermally stable space telescopes enable the desired science of potential HabEx and LUVOIR missions
- Integrated modeling tools enable better definition of system and component engineering specifications

## *Approach:*

- Science-driven systems engineering
- Mature technologies required to enable highest-priority science resulting in high-performance, low-cost, low-risk system
- Mature technology in support of 2020 Decadal process

## *Key Collaborators:*

- Thomas Brooks, Richard Siler, and Ron Eng (NASA/MSFC)
- Carl Rosoti, Keith Harvey, and Rob Egerman (Harris Corp)

## *Funded Period of Performance:*

Jan 2017 – Sep 2021
(awarded as competed SAT, converted to ISFM directed work)

## *Accomplishments:*

- ✓ Successfully completed all initial PTC objectives and milestones
- ✓ Demonstrated PTC multi-zone thermal control via test of a 1.5-m ULE® mirror in a relevant thermal/vacuum environment.
- ✓ Demonstrated figure correction via multi-zone thermal control
- ✓ Published study results in JATIS journal paper

## *Applications:*

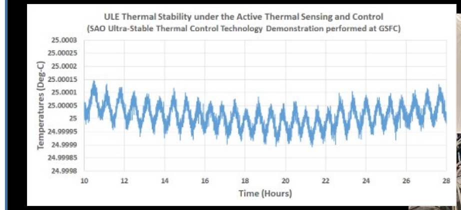
- Flagship and Explorer-class optical missions
- Department of Defense and commercial observations

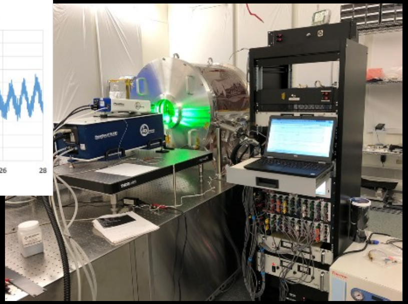
***TRL*** $_{In}$ ***= 3*** ***TRL*** $_{Current}$ ***= 5+*** ***TRL*** $_{Target}$ ***= 4 - 5***

# Other Examples of Technology Progress….

## Ultrastable Telescopes

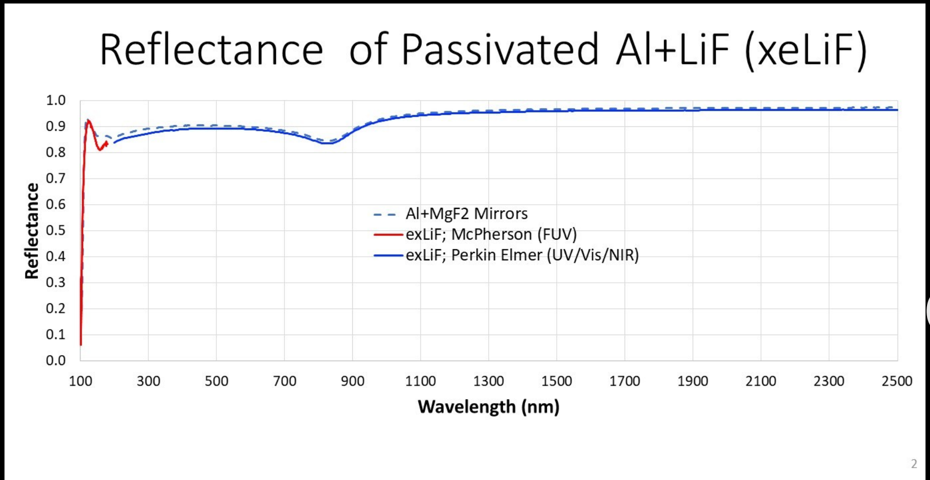
- +-75uK thermal control, pm/s drift measurements



Thermal stability was demonstrated to less than **0.15mK P-V (150uK or +/-75 µK) over an hour** with pm/s drifts measured interferometrically.

GSFC Ultrastable testbed/Picometer High Speed Interferometry




## Coatings M. Quijada/GSFC

- First Continuous PSF calibration Demonstrated

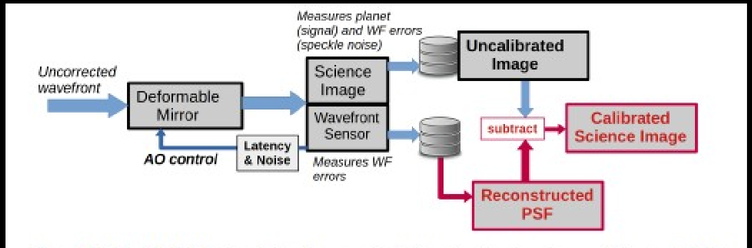
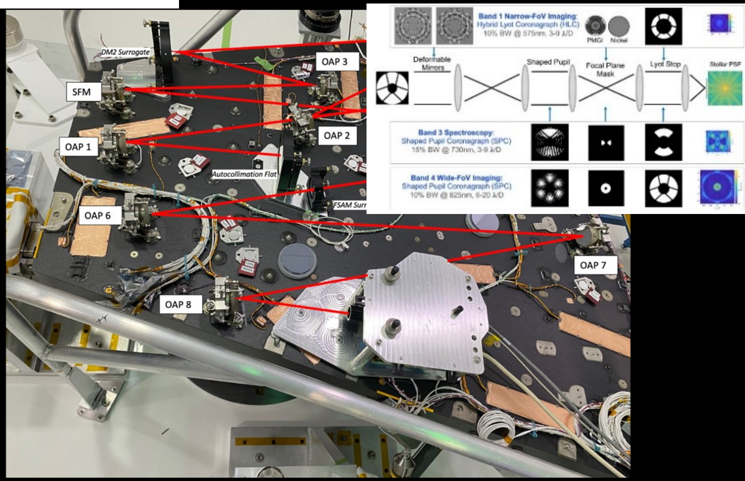



Figure 1. WFS-based PSF calibration principle. In a conventional high contrast imaging system, wavefront sensor (WFS) measurements are used to drive a wavefront control loop. We discuss in this paper how the WFS telemetry can also be used to reconstruct the point spread function (PSF) so that speckle noise can be subtracted in high contrast images (red boxes).

High Contrast Imaging with Photon Noise Limit Calibration, O. Guyon/SPIE/2022




Roman Space Telescope Coronagraph/JPL

# Next Steps

- Update Roadmaps Consistent both With Progress and The Decadal Recommendation and Develop Initial Investment Strategy
  - Need updated investment strategy for next fiscal year
    - Prioritize enabling technologies, tall polls, largely derived from LUVOIR and Habex Roadmaps
    - Consider facilities and facility needs in the future
- Science/Architecture/Technology Studies:
  - Focus first on key driving architectural decisions
  - Error budgets/sensitivities/calibration developed to flow requirements
- Critical that science, technology development and system/architecture studies happen in parallel and iterate